USB Voltage Drop and Droop Measurement

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2. Introduction

The USB specification stipulates that hot plugging a peripheral does not adversely affect the functionality of other peripherals that are connected to USB. In order to meet this condition it is necessary to characterize the behavior of the power delivered to other USB peripherals connected to the host or hub that is undergoing hot plug.

This paper analyzes the factors that affect voltage drop and droop, including IR drops in the host, cabling and peripherals; hot plugging is analyzed with regard to its effect on voltage droop. Included is a review of the parameters defined in the USB specification, description of the measurement technique, test results, and an interpretation of those results. A set of guidelines is given to enable the peripheral designer to meet voltage drop and droop figures and explains possible tradeoffs that the designer has available.

This paper analyzes voltage drop and droop for USB hosts, self powered hubs and for bus powered peripherals. Subsequent references in this document use the term “host” to refer to either the host or to self powered hubs. The following table summarizes the voltage limits for USB hosts, peripherals, and hubs.

Description	Value	Where Measured
Minimum DC voltage at host conn	4.65V	Downstream host or self powered hub receptacle
Minimum DC voltage at peripheral	4.40V	Downstream host or self powered hub receptacle
Minimum AC voltage at host conn	4.20V	Downstream host or self powered hub receptacle
Minimum AC voltage at peripheral	4.00 V	At peripheral
Minimum DC voltage at bus powered hub	4.40V	Downstream port of bus powered hub
Minimum AC voltage at bus powered hub	4.225V	Downstream port of bus powered hub
Minimum DC voltage at peripheral connected to BP hub	4.150V	At peripheral
Minimum AC voltage at peripheral connected to BP hub	4.00V	At peripheral

All of the above numbers are derived from the requirement in the USB specification that *the downstream end of the cable must never go below 4.00V.*

3. Review of USB Specification

USB voltage drop and droop figures appear in sections 7.2.2 and 7.2.4.1 of the 1.0 revision of the USB specification. The specification requires a minimum DC voltage of 4.75 V at the host connector or

downstream connector of a self powered hub. Droop voltage is specified to be 330 mv max measured at the upstream end of a connection.

A more careful analysis of droop and drop figures was prompted by the results of lab testing on actual hardware. Test results demonstrated that the voltage drop measurements must comprehend other IR components that were not previously factored into the voltage budget. Voltage droop also was shown to be more complicated than previously anticipated. In particular, the voltage droop during a hot plug event varied depending on which end of the cable the measurement was made.

3.1 Peripheral Behavior in Presence of Hot Plug Events

As stated in the USB spec, a hot plug event must not cause loss of USB functionality. This statement can be elaborated upon in the following set of rules.

1. A hot plug event must not cause any USB device that is currently plugged in to lose state
2. A hot plug event must not logically corrupt any USB signaling
3. It is permissible for a USB device to not meet V_{OH} signaling parameters during a hot plug event

Rule 1 implies that a hot plug event not cause any currently plugged USB device to lose any stored state information. This includes USB data, hardware states and in the case of µcontrollers, software and firmware. Rule 2 states that a hot plug event not affect the sense of signaling generated by a hot plug event. If a devices signals a J state a hot plug event must not cause the device to signal a K or SE0 state. Rule 3 states that the V_{OH} voltage margin, is permitted to undergo degradation in the event of a hot plug. The only devices that may fail to meet V_{OH} signaling levels are those peripherals downstream of a host or self powered hub into which a peripheral is hot plugged. The duration of the V_{OH} not meeting spec should be as short as possible, and the effect on robustness should be no worse than that caused by a decrease in the V_{OH} margin.

4. Peripheral Minimum Voltage Characterization

Bus powered USB peripherals have a minimum supply voltage below which reliable operation is not guaranteed. This limit can be calculated for USB peripherals that use an unregulated V_{BUS} and for those peripherals that utilize an external 3.3V regulator.

The minimum voltage for externally regulated USB peripherals is set by a combination of the regulator dropout voltage and the accuracy of the regulator's output. Regulator dropout is specified as the minimum voltage difference between the input voltage and the actual output voltage at which a regulator ceases to regulate. Once the input voltage to a regulator falls below the sum of $V_{OUT} + V_{DROPOUT}$ its output is no longer guaranteed within tolerance, and reliable operation of the USB peripheral powered by the regulator is no longer guaranteed. Assuming a 3.3V 5% output tolerance, and a 0.5V dropout voltage, the worst case input voltage conditions occur for a regulator with a 3.3V + 5% output voltage and a 0.5V dropout, and yields a minimum value for $V_{BUS(min)}$ of 3.965V. This value is sufficiently close to 4.00V so that it can be rounded up to that value, and 4.00V will be used in all further analysis. The regulator tolerance and dropout parameters were chosen such that they could be met by inexpensive regulators that are available from a number of manufacturers.

Peripherals operating directly off V_{BUS} are subject to minimum supply voltages based upon the need to meet timing requirements and the need to internally generate a 3.3V reference voltage which is used to set the output V_{OH} level. $V_{BUS(min)}$ is process dependent, but for typical 5.0V CMOS processes was found to be about 4.00V. The 4.00V limit is a realistic value for one chip solutions that must internally establish a 0 to 3.3V output swing; i.e., there is sufficient headroom to allow a diode drop or transistor threshold from V_{BUS} to $V_{OH(min)}$. Note: if a peripheral has a permanently attached cable it is permissible to specify a lower $V_{BUS(min)}$ at the peripheral end of the cable so long the peripheral can can meet $V_{OH(min)}$ at the upstream end of the cable.

This section establishes 4.00V as the minimum transient peripheral voltage.

5. DC Drop Parameters

5.1 Host Minimum Voltage Drop Characterization

A typical host consists of a motherboard with an external power supply, and two or more USB connectors, each capable of supplying 500 ma to downstream peripherals. The voltage drop from the power supply to the USB connectors is small, but not zero, and must be included in the voltage drop budget. There are three principal elements which contribute to the voltage drop, as shown in Figure 5-1. Most of the voltage drop is the result of the resistance of the fuse, which, for a poly fuse, can be as much as 70 mv at 1.0A of current. The remainder of the IR drop consists of trace resistance and DC resistance of ferrite beads yielding a total voltage drop of about 100 mv. The amount of current flowing through each of the elements in Figure 5-1 depends on the topology of the host's power connection to USB. Typically, a host will have a single fuse on V_{BUS} and a pair of beads for each USB connector. There are many power output topologies that are acceptable, and these are illustrated in Section 11. The amount of voltage drop across each of the components in the power output circuit varies with topology.

Two voltage limits are specified for a host power supply at the USB connectors.

1. The DC steady state minimum
2. A minimum voltage transient minimum occurring during hot plugging

The DC minimum is simply the worst case power supply voltage minus the DC voltage drop across the motherboard.

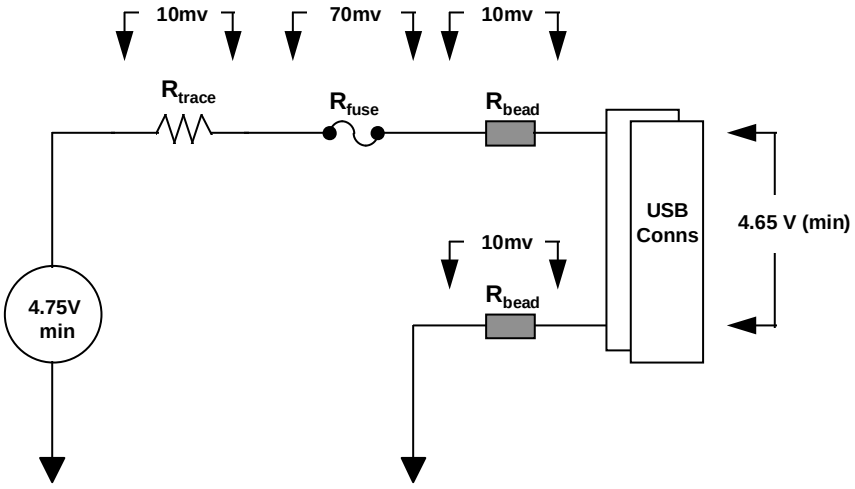


Figure 5-1: Host V_{DROP} Model

Most PC power supply manufacturers specify their supplies to 5.00V +/-5% and no better. The 5% tolerance is measured at the power entry connector on the motherboard and does not include any of the IR drops on the motherboard. As a result, the minimum voltage measured at the USB connector for hosts is decreased by the 100 mv drop on the motherboard from 4.75V to 4.65V. The voltage difference between the 4.65V available at the host USB connector and the 4.00V required by USB peripherals comprises the voltage budget available for cabling IR losses and voltage droop.

This section establishes 4.65V as the minimum DC V_{BUS} voltage at the peripheral end of a cable attached to a self powered port.

5.2 Peripheral Voltage Drop

The following section applies to all bus powered peripherals with the exception of bus powered hubs, and specifies the maximum allowable drop across the cable. There are two classes of USB peripherals so far as

cabling is concerned, those with permanently attached cables and those with detachable cables. If a peripheral has a permanently attached cable and is not a bus powered hub, the voltage drop across the cable is limited to 250 mv at the maximum peripheral operating current. This drop includes both the cable drop and the drop of the upstream USB connector and any downstream header. Bus powered hubs represent a special class of device with unique cabling requirements, and are discussed in Section 8.

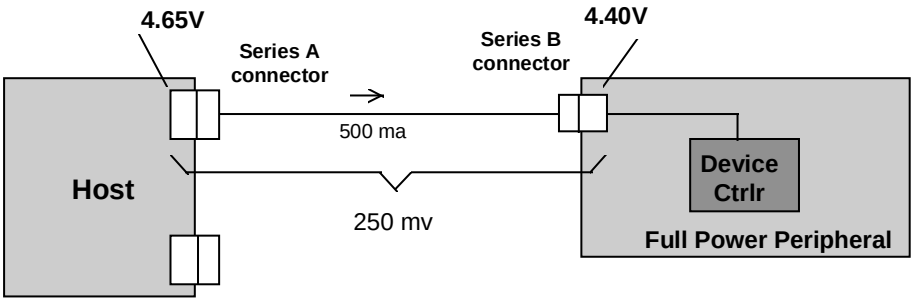


Figure 5-2: Minimum Voltage at Downstream Peripheral

If a peripheral supports a detachable cable then the voltage at the far end of the cable must be at least 4.40V, as described in the USB spec. This equates to a cable drop of no more than 250 mv at a 500 ma max load current. This number represents the maximum allowable DC drop and includes both the drop across the cable and across the mated pairs of USB connectors. For detachable cables, the resulting 4.65 V - 250 mv = 4.40 V represents the lowest continuous DC voltage that a bus powered peripheral will see. The difference between the 4.40V and the lowest allowed voltage at the peripheral controller of 4.00V represents the maximum allowable V_{DROOP} as measured at the peripheral.

This section establishes the minimum DC voltage at the peripheral end of a cable at 4.40V

6. Voltage Droop Characterization

Voltage droop occurs during a hot plug event as the result of the connection of a peripheral and its uncharged input bulk capacitance to the a USB port. For a few tens of μs the host must supply high current into the peripheral until its bulk capacitance is charged to V_{BUS}, creating a capacitive divider between the host's bulk capacitance and that of the just plugged in USB peripheral. The limit for voltage droop is set by the requirement that the voltage at USB peripheral controller never drop below 4.00V. Voltage droop, as measured at the peripheral, is proportional to V_{DROOP} appearing at the host connector and is influenced by numerous factors including the cable impedance, the amount of capacitance on the USB peripheral, and the power output circuit of the host/self powered hub. Since peripheral manufacturers will need to perform droop testing based upon a V_{DROOP} value measured at the host connector it is necessary to understand the relationship between V_{DROOP} at the host and V_{DROOP} at the peripheral.

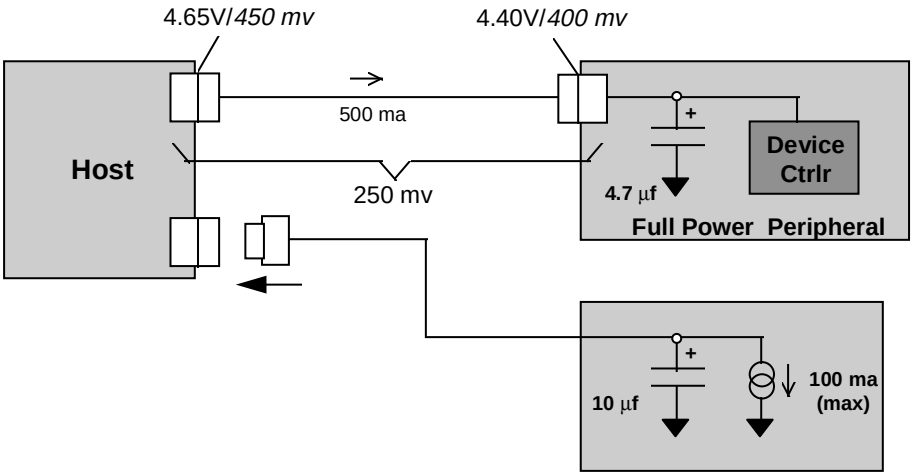


Figure 6-1: Voltage Droop for Host or Self Powered Hub

The complexity of the host power output circuit precluded performing an analytical study and necessitated making measurements on actual hardware. Actual host platforms were tested with worst case topologies and cable configurations. For example, the testing of cables indicated that a short cable with a high IR loss produced the worst case droop. This cable was then used in subsequent measurements. Another effect encountered early in testing was the improvement in voltage droop if the minimum peripheral bulk capacitance was increased from 2.2 µf to 4.7 µf. This change yielded approximately a 50 mv improvement and was incorporated into all subsequent tests.

Voltage drop and droop measurements were taken on four host platforms and are presented in Section 9. The most important result that can be drawn from the data is that V_{DROOP} at the peripheral is less than V_{DROOP} at the host connector. The amount by which V_{DROOP} improves is a function of the cable, capacitances on the peripheral and host and the host's power output circuit topology.

Host power output circuitry was the factor that showed the most influence over V_{DROOP}. Four different host platforms with differing output topologies were tested. The platforms utilized the output topologies shown in Figure 6-2. Platforms B, C and D shared similar output sections but had different PCB layouts.

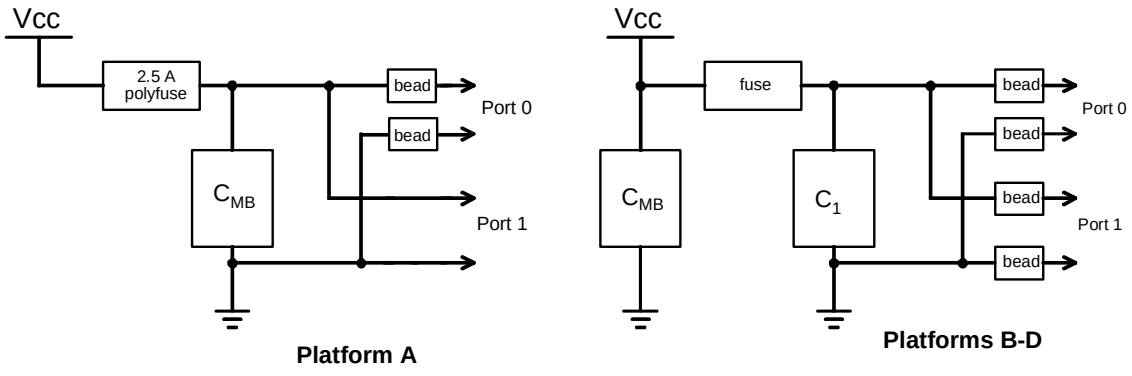


Figure 6-2: Host Power Output Topologies

Voltage droop data were take for each of these platforms under the conditions described in the following table. The test numbers, 1-15 correspond to the tests listed in Table 9-1 and Table 9-2.

Table 6-1: Host V_{DROOP} Test Conditions

Test #	Platform	C_{MB}	C_1	Fuse
1	A	None	None	2.5A poly
2	A	6.8 µf	None	2.5A poly
3	A	68 µf	None	2.5A poly
4	A	150 µf	None	2.5A poly
5	B	150 µf	None	4A 1-time
6	B	150 µf	None	2.5A poly
7	B	150 µf	6.8 µf	2.5A poly
8	B	150 µf	150 µf	2.5A poly
9	C	None	None	1.1A poly
10	C	150 µf	None	2.5A poly
11	C	150 µf	6.8 µf	2.5A poly
12	C	150 µf	150 µf	2.5A poly
13	D	150 µf	None	2.5A poly
14	D	150 µf	6.8 µf	2.5A poly
15	D	150 µf	150 µf	2.5A poly

Droop data and droop data improvement were compiled for each test. Since the host supplied about 5.10V at the host, the V_{DROOP} figures at both the peripheral and host were normalized to 4.65V, which represents the minimum DC voltage at the host. The results were graphed as a percent improvement in normalized V_{DROOP} as a function of normalized host droop. Illustrated below, the figures show a linear relationship between droop improvement and V_{DROOP}. From this graph a couple of important results can be drawn. The first result is this it is possible to state the minimum droop improvement is at least 16 percent. For a worst case host voltage of 4.65 V, the improvement at 16 percent equates to about 70 mv. This 70 mv can be allocated to increasing the droop that can be tolerated at the host connector from 400 mv to 450 mv. The additional 20 mv of remaining margin can be allocated to the peripheral to allow for trace resistance.

The second result is that droop improvement is proportional to V_{DROOP}. This is important because it can be demonstrated that the worst case voltage droop occurs at 4.65V. As V_{BUS} is increased V_{DROOP} increases, but not as quickly. Therefore the droop margin above the 4.00V minimum will increase as V_{BUS} increases.

From the two preceding results it is possible to determine the minimum AC voltage that can be seen at the host by subtracting the sum of the 400 mv droop figure plus the 50 mv droop improvement from the minimum host voltage of 4.65V to yield 4.65V - (0.400V + 0.050V) = 4.20V.

The lowest transient voltage that may appear at the host is 4.20V

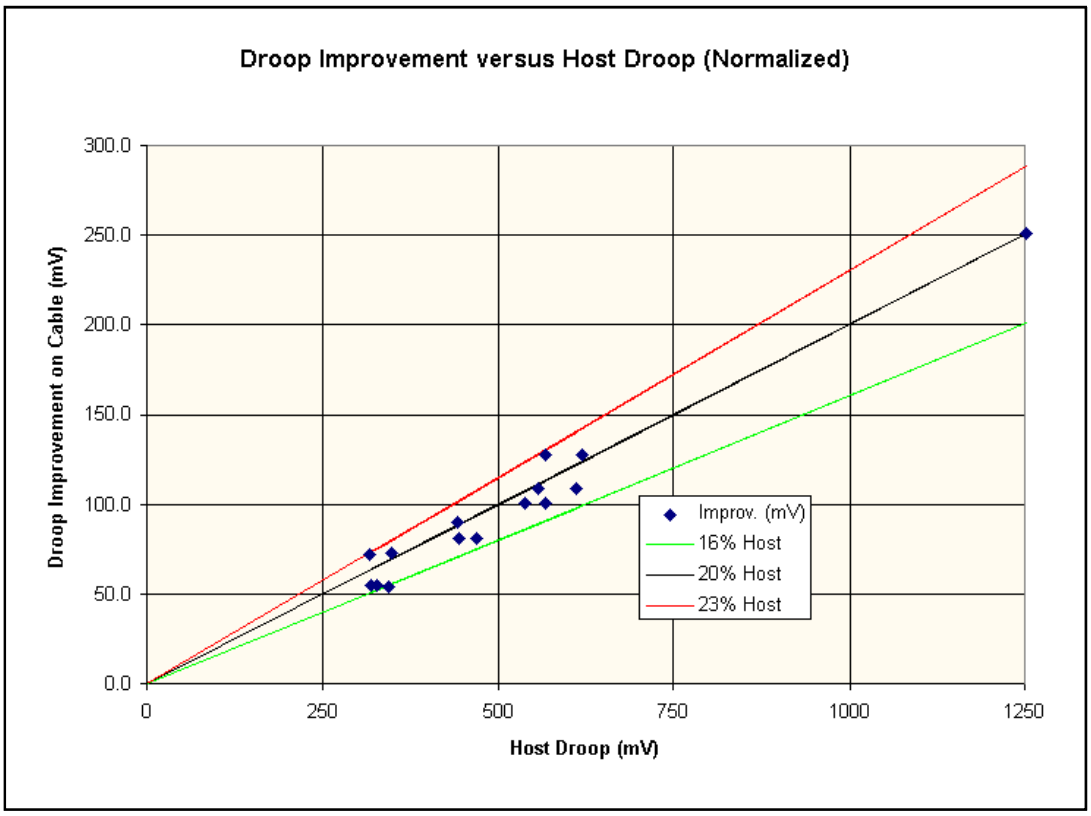


Figure 6-3: Droop Improvement Values

If the minimum host supply voltage is greater than 4.65V then it is possible to trade off voltage drop for voltage droop. The advantage of this scenario is the need for smaller bulk capacitors and the ability to tolerate higher series resistance in the ferrite beads. However, the host must still provide a minimum transient voltage of 4.20V at the its downstream connectors.

A similar set of tradeoffs can be made for peripherals when the voltage drop across the cable is less than 250 mv. These include the ability to reduce the amount peripheral bulk capacitance on the peripheral and the ability to support peripheral devices whose V_{MIN} is greater than 4.00V. V_{CABLE} will be less than 250 mv if the device draws less than 500ma and has a detachable cable or if the device has an integral cable and the cable is designed to drop less than 250 mv.

Devices with V_{MIN} less than 4.0V may also be supported as long as their signaling voltages are within the $V_{OH(min)}$ and $V_{OL(max)}$ limits given in Chapter 7 of the USB spec.

7. Peripheral Testing Methodology

From an ease of testing point of view, it is highly desirable to voltage test peripherals from the host side. This is particularly true for devices with permanently attached cables. The apparatus shown in Figure 7-1 can be used for the testing.

The programmable power source (PPS) is capable of providing at least 500 ma of current at a stabilized voltage of 4.65V and is also capable of generating a triangular dip in the bus voltage of amplitude such that the minimum voltage appearing at the upstream end of the cable is 4.20V. The width and shape of the triangular dip are as follows:

1. Voltage dip from 4.65V to 4.20V
2. Negative edge rate for 2.0 µsec
3. Positive edge 20 µsec.

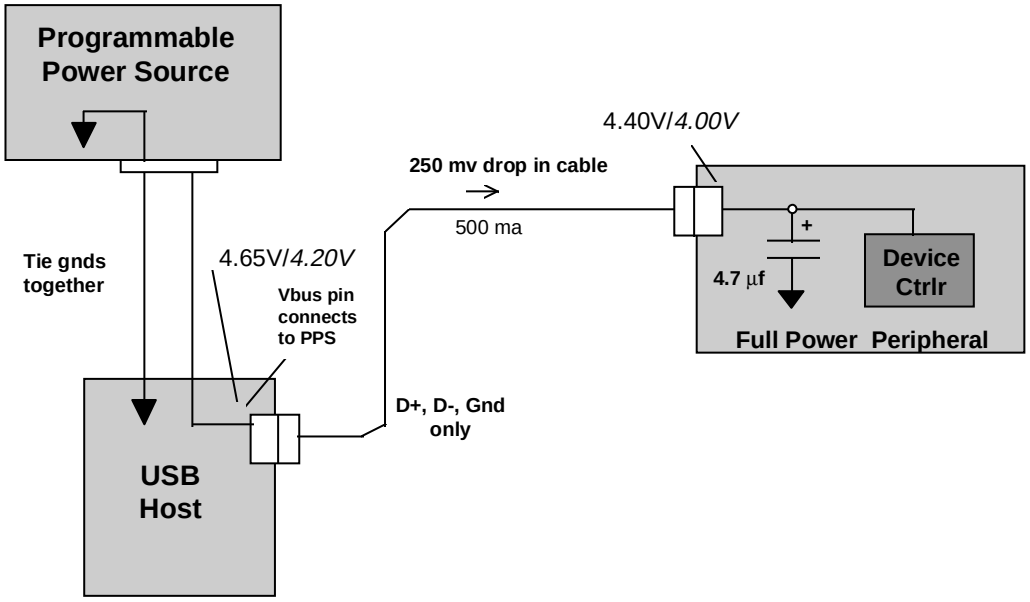


Figure 7-1: Voltage Droop Test

Since V_{BUS} is generated by the PPS, the USB host connector is modified to furnish connections to D+, D- and ground of the host only. This is accomplished by isolating the V_{BUS} pin of the host connector and connecting it to the output of the PPS. Be sure the PPS connects directly to the V_{BUS} pin of the USB host. The USB host and the PPS must have their grounds connected together, and the connection should be as short as possible and made with a heavy gauge of stranded wire or through a coaxial cable. Once set up, the test equipment can be calibrated for the correct DC voltage and AC droop component. Measurements are made between at the host connector between the V_{BUS} and Gnd pins. The following figure shows the shape of the voltage transient.

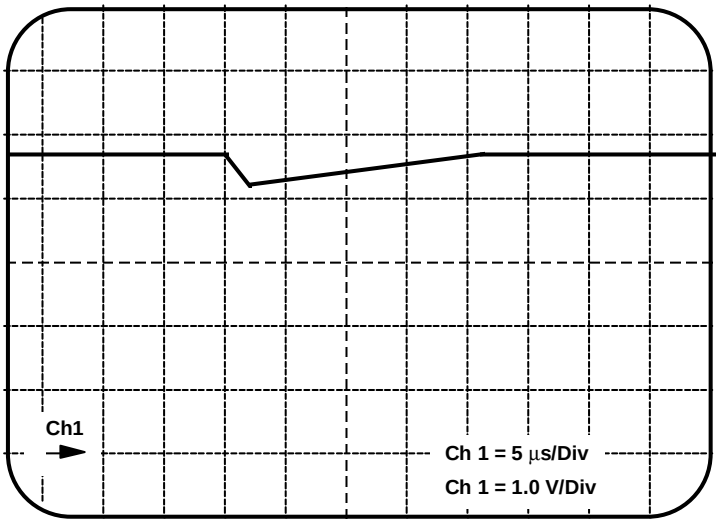


Figure 7-2: AC Transient Test Voltage

A peripheral is tested by having the host initialize it and then run bi-directional full speed bus traffic to the peripheral. The packet size should be long enough to yield a high probability of a simulated hot plug event occurring while data is being sent to or received by the device under test. If the peripheral can successfully send and receive data without receiving non-recoverable errors for one minute then the peripheral is considered to pass the voltage droop test. Retries are permitted on non-ISO endpoints, and the effect of hot plug on ISO endpoints must be no worse than that caused by externally induced bus noise, such as static discharges.

8. Bus Powered Hubs

Bus powered hubs were not specifically investigated in this paper, but there are some conclusions that can be drawn based upon voltage parameters that were obtained for hosts and bus powered peripherals.

1. Bus powered hubs deliver a minimum DC voltage of 4.40V to downstream peripherals
2. Bus powered hubs limit total drop (hub plus cable) to less than 250 mv

Since bus powered hubs require a power switch, and this switch and PC board trace resistance will drop ~100 mv, the voltage drop available for the USB cable is only 150 mv. This is less than the standard 250 mv for detachable cables and can be met either by requiring that bus powered hubs have an integral cable or by specifying a type C receptacle and connector which would be attached to cables that drop no more than 150 mv at a 500 ma load. The best way to accommodate the needs of bus powered hubs is still under investigation.

A bus powered hub is not guaranteed to furnish more than 4.40V at its downstream ports. When cable drop is included the minimum DC voltage available at the peripheral is 4.40V - 0.250V = 4.150V. Therefore the voltage droop at the peripheral is limited to 150 mv. Applying the same 16 percent minimum V_{DROOP} improvement yields a voltage droop of 175 mv at the downstream port of a bus powered hub. The method needed to meet this stringent voltage droop parameter is still being investigated. However, the most likely implementation will be an output topology that is similar to that shown in Figure 11-2 . The principal difference is that a bus powered hub does not require overcurrent limiting but does require power switching on V_{BUS} to all downstream ports. The switch will require inrush current limiting so that the downstream bulk capacitors can be charged slowly when the switch if first turned on. An example of a bus powered hub's power output circuit is shown below. The example in Figure 8-1 utilizes a ganged power switch.

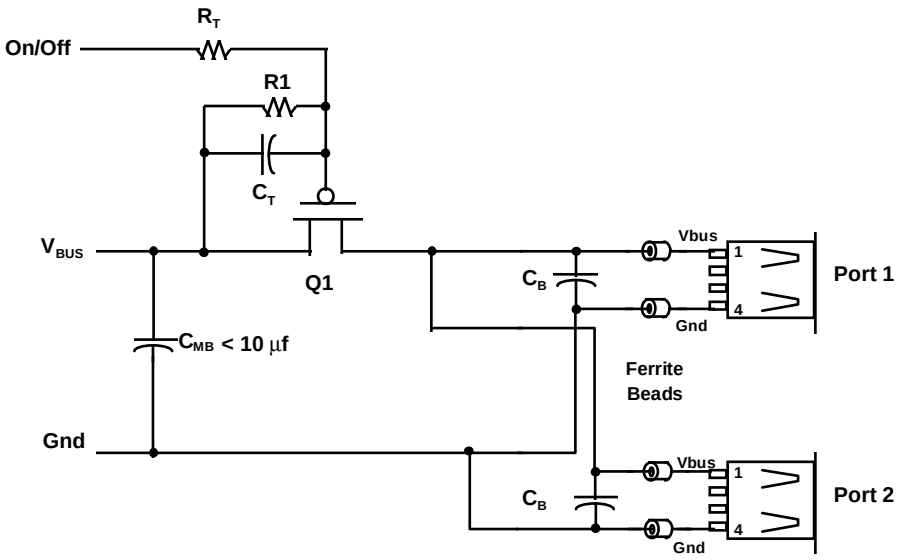


Figure 8-1: Bus Powered Hub Power Output

Q1's gate is pulled to V_{BUS} by R1, and the on/off strobe is driven by an open drain device. When the hub is first plugged in Q1 is held off. Turning Q1 on requires that the on/off strobe be pulled low, and Q1's turn on rate is controlled by R_T and C_T. The rate at which Q1 is turned on must be such that the voltage droop measured at the hub controller does not exceed 150 mv. C_B is the per port bulk capacitance and needs to be determined empirically. Note that the maximum amount of capacitance a bus powered hub may reflect upstream when first plugged in is 10 µf.

9. Appendix 1: Voltage Droop Measurement Results

The following table lists the raw voltage droop measurements made on different host platforms

Table 9-1: Raw Voltages Measured at Host

		Voltages measured at Host				
Test Number	**Platform**	**V_{BUS}**	**V_{DROOP}**	**V_{BUS}(min)**	**Dip Width**	**Cable Drop**
		(V)	(mv)	(V)	(uS)	(mv)
1	A	5.15	520	4.63	16	240
2	A	5.15	490	4.66	10	240
3	A	5.15	380	4.77	not measured	240
4	A	5.15	350	4.80	14	240
5	B	5.14	490	4.65	12	240
6	B	5.10	680	4.42	14	230
7	B	5.10	610	4.49	12	240
8	B	5.11	360	4.75	12	240
9	C	5.01	1350	3.66	20	230
10	C	5.08	620	4.46	16	230
11	C	5.08	620	4.46	16	230
12	C	5.08	380	4.70	16	240
13	D	5.10	670	4.43	14	240
14	D	5.09	590	4.50	14	230
15	D	5.10	350	4.75	16	240

Voltage measurements were also made at the peripheral end as shown below.

Table 9-2: Raw voltage drop/droop measurements at peripheral end

		Peripheral Numbers			Droop	Device as %
Test #	**Platform**	**V_{BUS}**	**V_{DROOP}**	**V_{BUS}(min)**	**improvement**	**of host**
		(V)	(mv)	(V)	mv	percent
1	A	4.91	430	4.48	90	17.3
2	A	4.91	390	4.52	100	20.4
3	A	4.91	320	4.59	60	15.8
4	A	4.91	270	4.64	80	22.9
5	B	4.90	400	4.50	90	18.4
6	B	4.87	540	4.33	140	20.6
7	B	4.86	490	4.37	120	19.7
8	B	4.87	300	4.57	60	16.7
9	C	4.78	1080	3.70	270	20.0
10	C	4.85	510	4.34	110	17.7
11	C	4.85	480	4.37	140	22.6
12	C	4.84	300	4.54	80	21.1
13	D	4.86	550	4.31	120	17.9
14	D	4.86	480	4.38	110	18.6
15	D	4.86	290	4.57	60	17.1

The above figures were made for a V_{BUS} that varied between 5.01 and 5.15 volts. In order to determine the droop figures for a worst case host voltage the voltage and voltage droop figures are scaled. V_{DROOP} will scale linearly with the magnitude of V_{BUS}, and V_{DROOP} is scaled by the ratio of $V_{BUS(measured)}$ to $V_{BUS(min)}$, which for these figures was about 0.90. The resulting table gives normalized voltage droop figures scaled to the worst case DC value at the host.

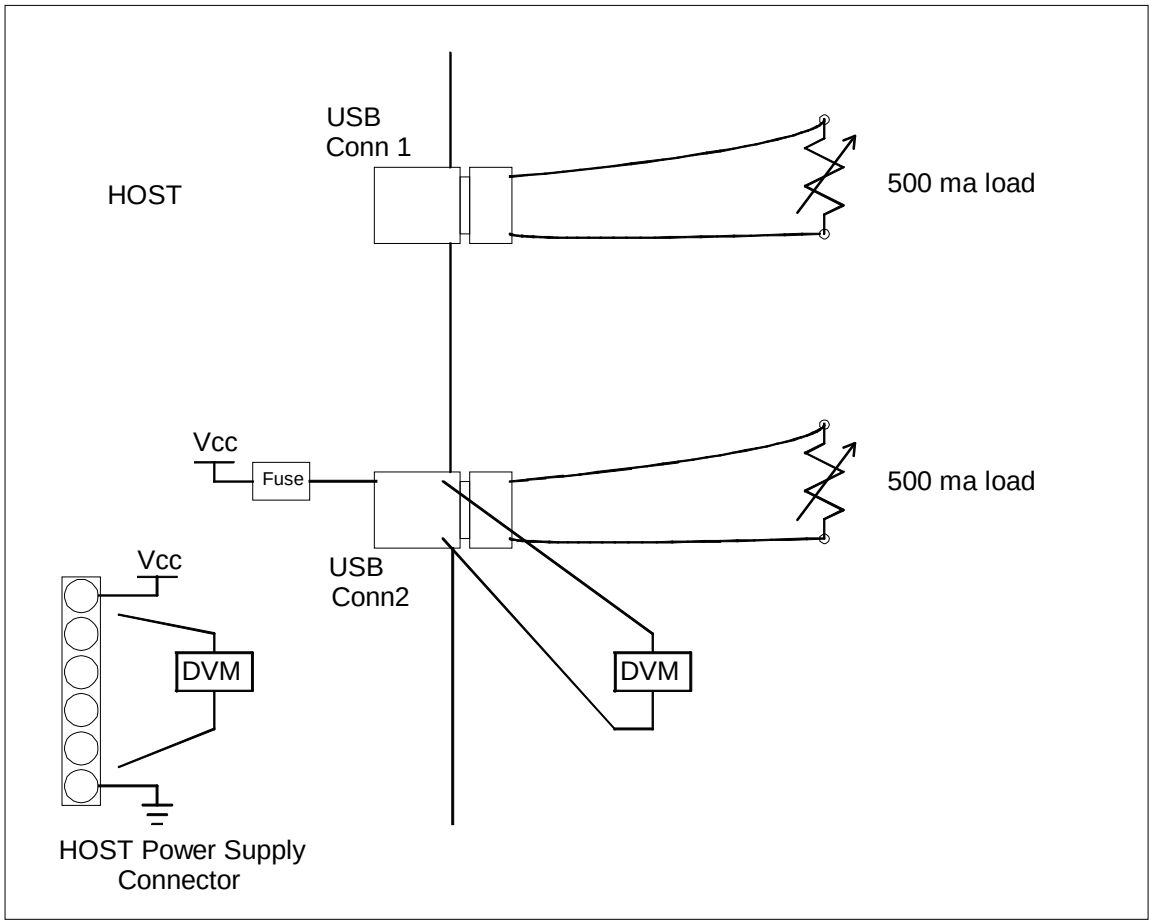
Table 9-3: Normalized V_{DROOP} Figures

Test #	Platform	Host Droop to 4.65V (mv)	Host V_{BUS} (min) (V)	Droop Improv. (mv)	V_{BUS} at Peripheral (V)	Peripheral V_{DROOP} (mv)	Peripheral V_{CC}(min) (V)	% Improv.
1	A	470	4.18	81.3	4.41	385	4.01	17.3%
2	A	442	4.21	90.3	4.41	349	4.05	20.4%
3	A	343	4.31	54.2	4.41	287	4.11	15.8%
4	A	316	4.33	72.2	4.41	242	4.16	22.9%
5	B	443	4.21	81.4	4.41	359	4.04	18.4%
6	B	620	4.03	127.6	4.42	488	3.91	20.6%
7	B	556	4.09	109.4	4.41	444	3.96	19.7%
8	B	328	4.32	54.6	4.41	271	4.13	16.7%
9	C	1253	3.40	250.6	4.42	994	3.41	20.0%
10	C	568	4.08	100.7	4.42	463	3.94	17.7%
11	C	568	4.08	128.1	4.42	435	3.96	22.6%
12	C	348	4.30	73.2	4.41	273	4.13	21.1%
13	D	611	4.04	109.4	4.41	498	3.90	17.9%
14	D	539	4.11	100.5	4.42	435	3.97	18.6%
15	D	319	4.33	54.7	4.41	263	4.14	17.1%

10. Appendix 2: Measurement Techniques

10.1 Host V_{DROP} Measurement

The technique for measuring IR voltage drop on a USB host is illustrated in the following figure.



1. Connect the test apparatus illustrated above to both host USB connectors
2. Allow the equipment to operate for at least 5 minutes to stabilize component temperatures.
3. Using a DVM measure the Vcc voltage at the host's power supply connector.
4. Using a DVM measure the USB V_{BUS} voltage at the host's USB connector (pin 1 V_{BUS}, Pin 4 Gnd).
5. Repeat the measurement for the other host USB connector.

Host Power Supply Voltage: _____

USB connector 1 voltage: _____

USB connector 2 voltage: _____

10.2 Measuring Hot Attach Voltage Droop

The typical source for USB Vcc is the host's 5V power supply, which is commonly delivers 5.25V to 4.75V.

10.2.1 Measuring Droop with large IR cable loss

The test apparatus is show in the following illustration

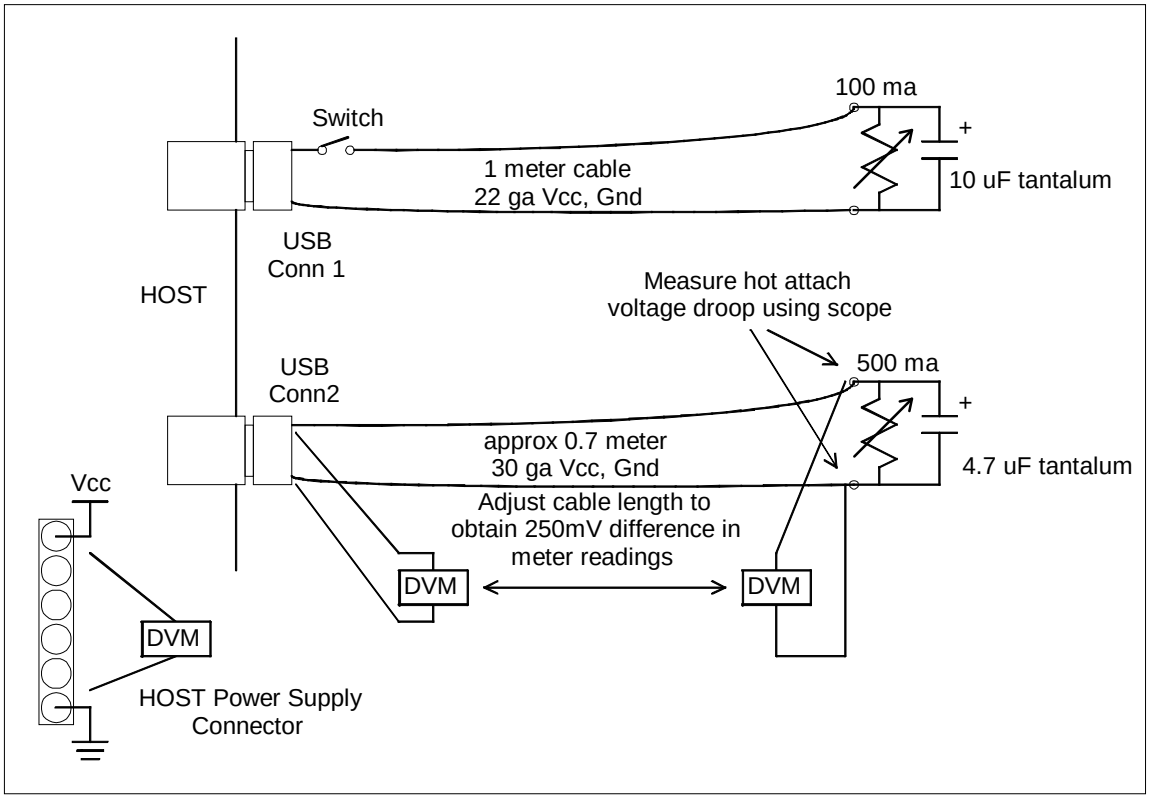


Figure 10-1: Measuring Droop with large IR cable loss.

1. Connect the test apparatus shown above to the two host USB connectors.
2. Connect an oscilloscope probe at the load V_{BUS}, and connect the probe ground to load ground.
3. Set the scope trigger for normal mode, negative edge with trigger level just below the USB V_{BUS} voltage. Scope timebase should be set at 25 usec/ div.
4. Close the switch to connect the hot attach load, capturing the transient voltage droop on the scope.
5. Using the scope horizontal cursor measure the voltage droop as indicated in figure 2.
6. Disconnect the hot attach 44Ω resistor and 10μF capacitor by opening the switch.
7. Using a DVM, measure the voltage across the motherboard's power supply connector.
8. Using a DVM measure the V_{BUS} voltage across the USB load (across the 10 ohm resistor).

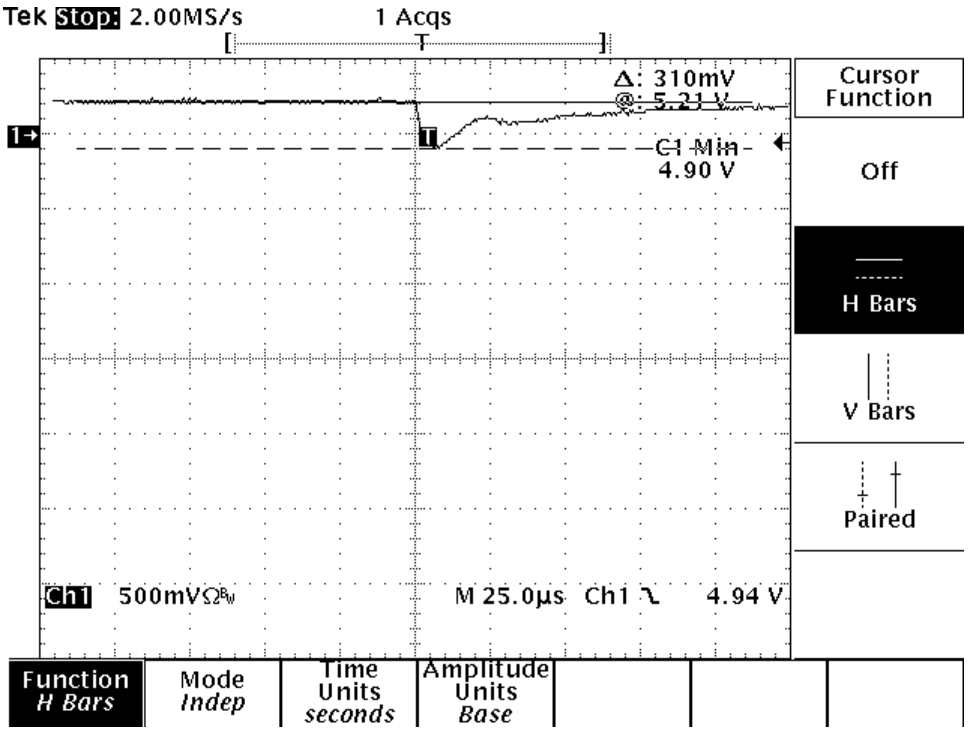


Figure 10-2: Voltage Droop measurement

Record the Hot Attach voltage droop measurements for each USB port.

V_{DROOP} _____

V_{BUS} at power supply connector _____

V_{BUS} at USB load _____

Performance standard required:

10.2.2 Measuring V_{DROOP} with small IR cable loss

The test apparatus is shown in the following figure.

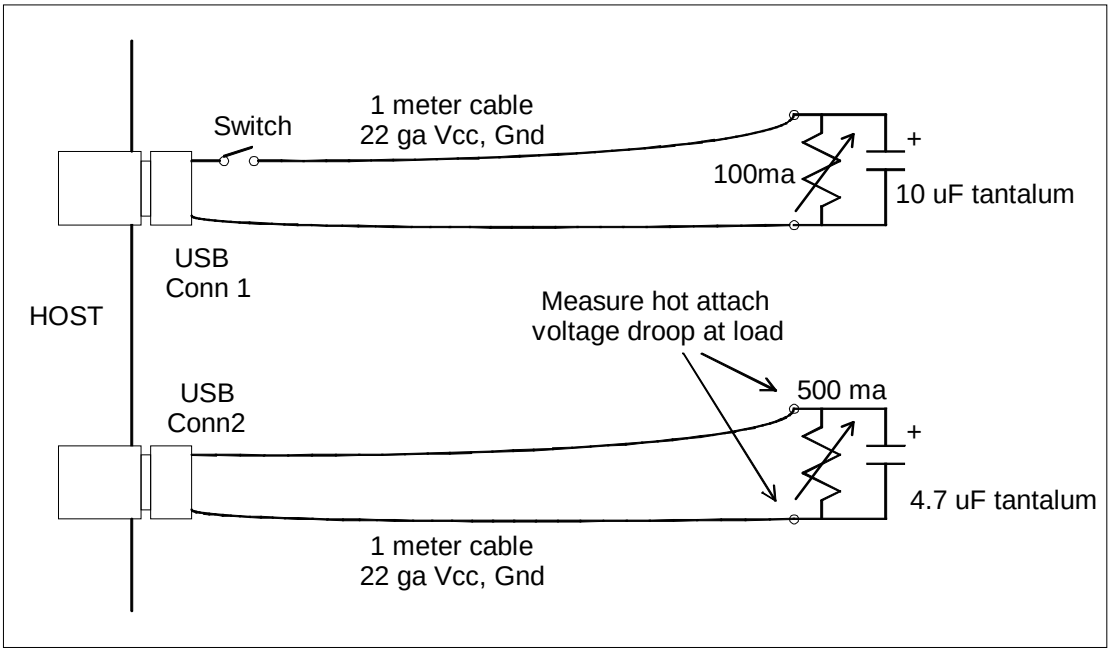


Figure 10-3: Measuring droop with small IR cable loss

1. Connect the test apparatus shown above to the two host USB connectors.
2. Connect an oscilloscope probe at the load V_{BUS}, and connect the probe ground to load ground.
3. Set the scope trigger for normal mode, negative edge with trigger level just below the USB V_{BUS} voltage. Scope timebase should be set at 25 µsec/ div.
4. Close the switch to connect the hot attach load, capturing the transient voltage droop on the scope.
5. Using the scope horizontal cursor measure the voltage droop as indicated in Figure 10-3
6. Using a DVM, measure the voltage across the motherboard's power supply connector.
7. Using a DVM measure the V_{BUS} voltage across the load

Load V_{DROOP} _____

V_{BUS} at power supply connector _____

V_{BUS} at USB load _____

Performance standard required:

11. Appendix 3: Downstream Power Connections

The following power output section topologies are typical of those found in the test platforms. Each is evaluated with respect to its ability to meet USB voltage drop and droop requirements.

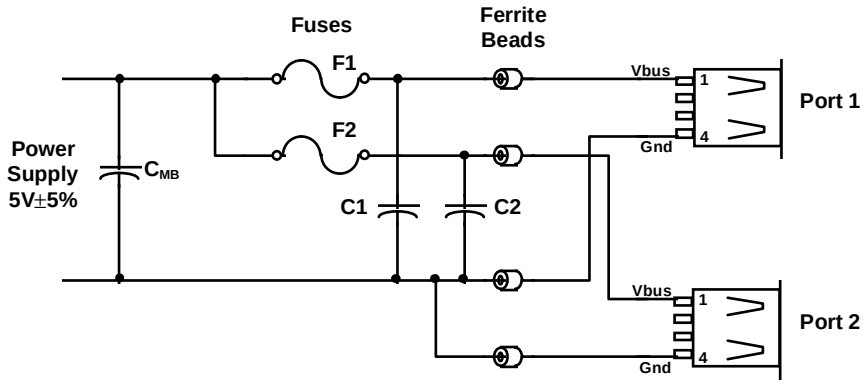


Figure 11-1 - Best Downstream Power Connection For Hosts / Self-Powered Hubs

Figure 11-1 represents an optimal design for a downstream USB power connection. IR drop is minimized through use of separate fuses and ferrite beads. Each port has dedicated bulk capacitance. When a hot plug occurs on one port its effect on the second port is minimized because C1, C2 and C_{MB} form a three-way capacitive divider. The per port ferrite beads also have a small resistance, and that resistance acts as an inrush current limiter. Note, that in all of these figures, C1, C2, and C_{MB} represent a bulk capacitor in parallel with one or more high frequency capacitors of the 0.1 to 0.01 μf range. For the topology shown above, C1 and C2 can be smaller than in subsequent figures, and no additional motherboard capacitance is needed.

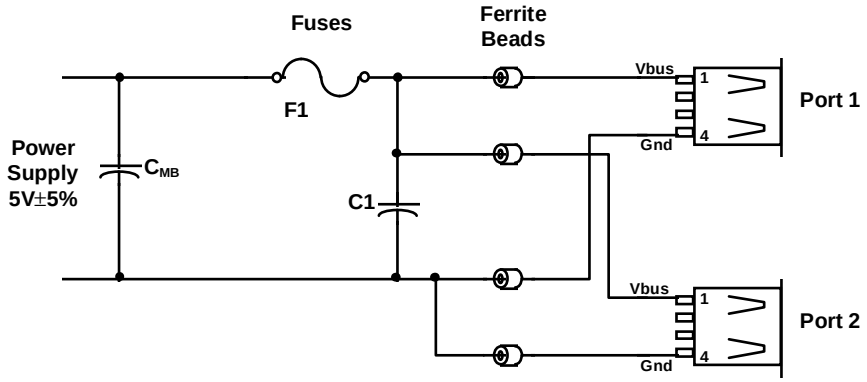


Figure 11-2 - Good Downstream Power Connection For Hosts / Self-Powered Hubs

Figure 11-2 is a less expensive but still effective implementation of a USB power output stage. The principal difference is that the per port capacitors and fuses are now shared. If F1 is increased to compensate for the need to carry twice the current then the DC voltage drop through this output circuit remains the same. Droop voltage response will not be quite as good as Figure 11-1, because C1 must now both supply current to both the peripheral already plugged in as well as the peripheral just hot plugged. The resistance of the ferrite beads becomes more critical in this instance because their resistance limits the inrush current seen by C1.

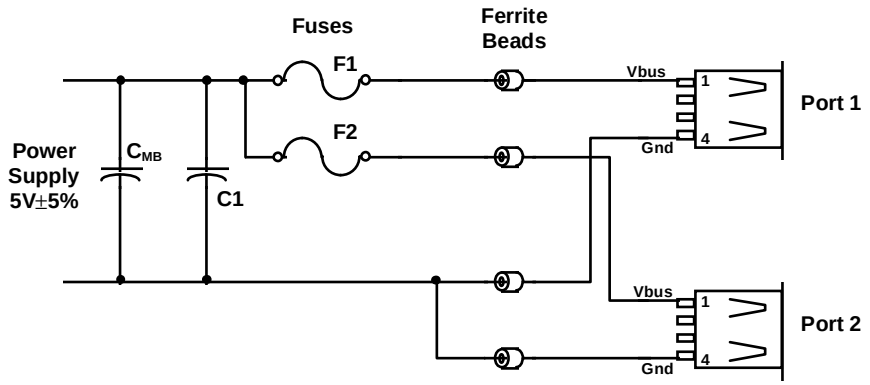


Figure 11-3 - Acceptable Downstream Power Connection For Hosts / Self-Powered Hubs

This output circuit is less effective in meeting the V_{DROOP} spec because the bulk capacitor is on the upstream side of the fuse, resulting in a high series resistance between the capacitor and the port. When a peripheral is hot plugged the fuse does tend to limit inrush current, but it also limits the ability of C1 to source current to the port.

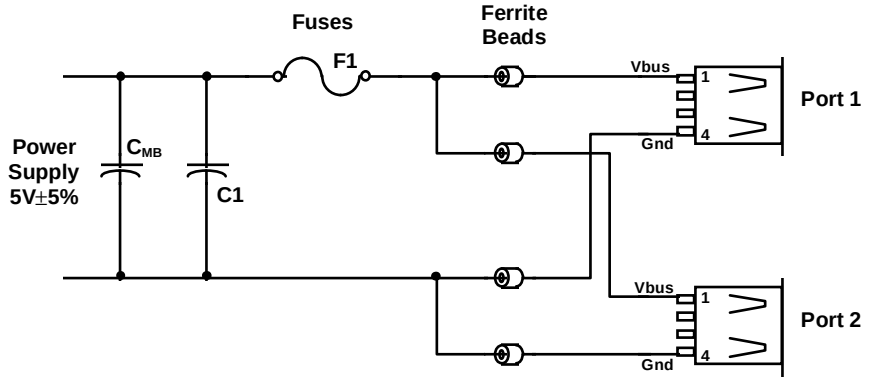


Figure 11-4 -Unacceptable Downstream Power Connection For Hosts / Self-Powered Hubs

Figure 11-4 through Figure 11-6 illustrate unacceptable output configurations. Topologies of this sort have been tested and were found to fail V_{DROOP} tests. In all cases, the major problem was that the ratio of the impedance that controls inrush current and the impedance that limits how fast C1 can supply charge is too large. In particular, the circuit in Figure 11-4 suffers from having a high impedance in series with the bulk capacitance. Tests have shown that when a one-time metal fuse is used then the circuit meets droop requirements. However, it fails when the higher resistance poly fuses are used.

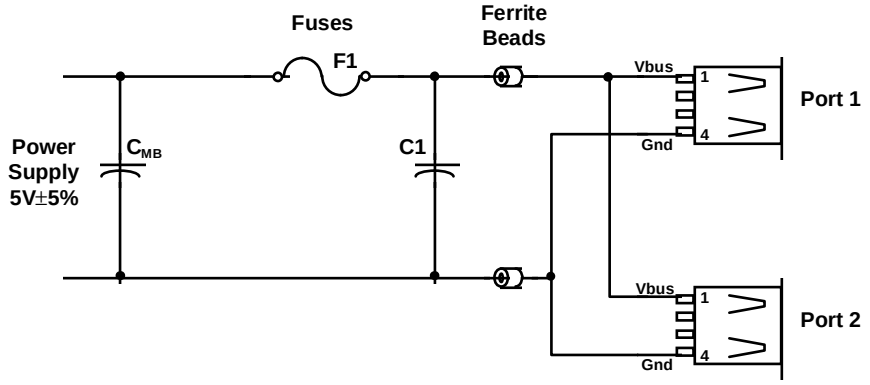


Figure 11-5 - Unacceptable Downstream Power Connection For Hosts / Self-Powered Hubs

The circuits in Figure 11-5 and Figure 11-6 suffer the problem that there is no inrush current isolation offered by per port ferrite beads. Whatever voltage drop occurs on port 1 also gets reflected onto port 2. The bulk capacitors are also isolated from the ports by the relatively high resistance of the fuse.

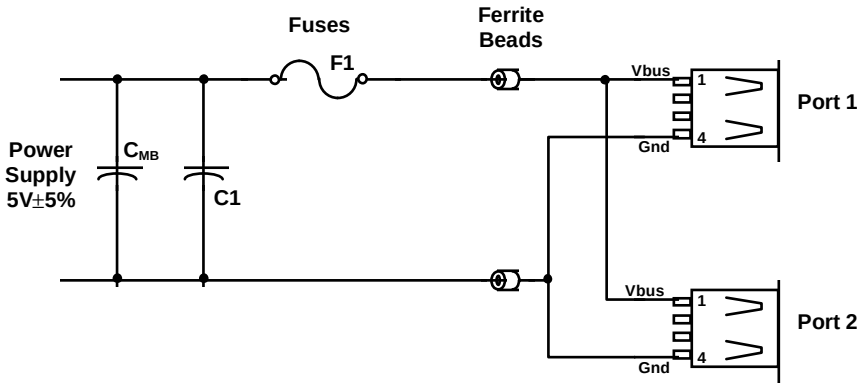


Figure 11-6 - Unacceptable Downstream Power Connection For Hosts / Self-Powered Hubs